AD-A077 992 AMERICAN INST FOR RESEARCH WASHINGTON DC F/G 15/3

A PRELIMINARY INVESTIGATION OF WEAPON-SYSTEM DISPERSION AND CRE--ETC(U)

JUL 78 P FINGERMAN DAHC19-76-C-0003

UNCLASSIFIED ARI-TR-78-B5 NL

1 OF 1

AD
A077992

END
DATE
FILMED
1-80
DDC

LEVEL II

ARI TECHNICAL REPORT
TR-78-B5

A PRELIMINARY INVESTIGATION OF WEAPON-SYSTEM DISPERSION AND CREW MARKSMANSHIP

by

Paul Fingerman
American Institutes for Research
1055 Thomas Jefferson Street, N.W.
Washington, D.C. 20007

July 1978

2Q763743A773

Contract DAHC 19-76-C-0003

Contracting Officer's Technical Representative
G. Gary Boycan, Unit Training and Evaluation
Systems Technical Area, Army Research Institute

Prepared for

U.S. ARMY RESEARCH INSTITUTE
for the BEHAVIORAL and SOCIAL SCIENCES
5001 Eisenhower Avenue
Alexandria, Virginia 22333

U. S. ARMY RESEARCH INSTITUTE

FOR THE BEHAVIORAL AND SOCIAL SCIENCES

A Field Operating Agency under the Jurisdiction of the Deputy Chief of Staff for Personnel

WILLIAM L. HAUSER
Colonel, US Army
Commander

JOSEPH ZEIDNER
Technical Director (Designate)

Research accomplished
under contract to the Department of the Army

American Institutes for Research

NOTICES

DISTRIBUTION: Primary distribution of this report has been made by ARI. Please address correspondence concerning distribution of reports to: U. S. Army Research Institute for the Behavioral and Social Sciences, ATTN: PERI-P, 5001 Eisenhower Avenue, Alexandria, Virginia 22333.

FINAL DISPOSITION: This report may be destroyed when it is no longer needed. Please do not return it to the U. S. Army Research Institute for the Behavioral and Social Sciences.

NOTE: The findings in this report are not to be construed as an official Department of the Army position, unless so designated by other authorized documents.

ARI TECHNICAL REPORT
TR-78-B5

A PRELIMINARY INVESTIGATION OF WEAPON-SYSTEM DISPERSION AND CREW MARKSMANSHIP

by

Paul Fingerman
American Institutes for Research
1055 Thomas Jefferson Street N.W.
Washington, D.C. 20007

July 1978

Contract DAHC 19-76-C-0003

Accession For	
NTIS GRA&I	☒
DDC TAB	☐
Unannounced	☐
Justification______	
By______	
Distribution/	
Availability Codes	
Dist.	Avail and/or special
A	

Contracting Officer's Technical Representative
G. Gary Boycan, Unit Training and Evaluation Systems
Systems Technical Area, Army Research Institute

P-1

Prepared for

U.S. ARMY RESEARCH INSTITUTE
for the BEHAVIORAL and SOCIAL SCIENCES
5001 Eisenhower Avenue
Alexandria, Virginia 22333

Army Project Number 2Q763743A773 Combat Unit Training

This is a report on an advanced development research project designed to meet military management requirements for research on a specific management problem. A limited distribution is made, primarily to the operating agencies directly involved.

A PRELIMINARY INVESTIGATION OF WEAPON-SYSTEM DISPERSION AND CREW MARKSMANSHIP

BRIEF

Requirement:

To determine the degree to which hardware-related dispersion could influence performance tests in tank gunnery. Normal main gun round-to-round dispersion may introduce inaccuracies in the scores achieved by tank crews during crew gunnery qualification. The development and use of a criterion-referenced qualification table makes the hit/miss determination for every round fired critically important.

Procedure:

Existing data provided by the Armor Engineer Board, U.S. Army Armor School, were analyzed. These data consisted of 126 main gun rounds fired from an instrumented tank under a variety of conditions. These conditions included: stationary tank; moving tank at 10 mph over a secondary road; moving tank at 5 mph cross-country; and moving tank at 10 mph cross-country. All rounds were fired at stationary, panel-type targets, at ranges of 800 to 1500 meters. Instrumentation included a video camera with telephoto lens sighted on the target, a second video camera mounted in the IR periscope, and video recorders for both cameras. Thus, for each round fired, both the sight picture and the actual strike of the round could be determined, relative to the center of the target.

Findings:

Several analyses of the data were conducted, including correlations between the sight picture and strike data, and tests of significance for the difference between sight picture and strike of the round. In addition, analyses were conducted which statistically factored out the performance of the tank crews tested in order to focus exclusively on the dispersion inherent in the weapon system. These results were used to develop a series of tables which indicate the maximum ranges at which a gunner, who assumed a perfect sight picture, could be expected to hit the target at least 95% of the time.

(9-2

The results indicate that when the weapon system is used as a testing device, steps must be taken to insure accurate indications of gunner performance that otherwise may not be available from strike-of-the-round data.

Utilization of the Findings:

This study was conducted on a small sample of data, and used relatively new test instrumentation. It is therefore recommended that a larger-scale study be performed in order to determine the reliability of the findings. If they are replicated, alternative gunnery testing strategies, including the use of gun cameras for scoring, use of scaled ranges or larger targets, etc., may have to be considered when implementing the criterion-referenced tank gunnery qualification table.

ACKNOWLEDGMENTS

The author gratefully acknowledges the assistance of several individuals in conducting the research reported herein. Major George E. Hamm, Captain Josef Shroeder, and SSC Eric K. Chandler of the Armor Test Division, U.S. Army Armor Engineer Board were instrumental in the conduct of the data collection, and provided the scored strike-of-the-round data. Mr. Richard E. O'Brien was chief of the subcontractor team which scored the aiming-point data. Mr. David Bryant of the Instrumentation Branch, Armor Engineer Board, provided detailed information on the instrumentation used to collect the data.

Special thanks are also due to Mr. George R. Wheaton, Principal Investigator on this project, who contributed greatly in the preparation of this report.

TABLE OF CONTENTS

p-5

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

The purpose of the present project is to develop a model Table VIII for determining the qualification of tank crews in gunnery. The model table described in a companion report (Wheaton, Fingerman, & Boycan, 1977), consists of 28 engagements in which targets are to be neutralized with various weapons of a tank. The model table is designed as a criterion-referenced instrument; that is, the performance of each crew on each engagement is compared to a specified standard of acceptable performance. A "pass" or "go" is recorded if the performance meets or exceeds the standard, while a "no-go" is recorded otherwise. These performance standards generally require a certain degree of accuracy (e.g., "obtain a target hit with at most two rounds") and speed in accomplishing the engagement (e.g., "engage within 5 seconds of target appearance, fire first round within 5 seconds, fire second round (if needed) within 10 seconds"). Both speed and accuracy standards must be met in order to score a "go" on any specific engagement. In addition to the specific performance standard, a second standard is also established to determine crew gunnery qualification. This standard is specified in terms of the proportion of engagements on which a "go" must be achieved.

A concern with this test (and, indeed, with all kinds of tests) is "error of measurement." At the heart of this concept is the notion that, while one uses empirically obtained <u>data</u> to represent a test score (e.g. "pass" or "fail"), one is actually interested in the testee's <u>true score</u>. Since measurement procedures invariably introduce some error, the empirically observed "pass" or "fail" datum is only an estimator of a true score, in this case the crew's true ability to perform the engagement. Measurement error leads to two additional concepts--"false positives," and "false negatives." A false positive occurs when a crew's true ability is less than that required by a test standard, but their empirically measured performance meets or exceeds that standard; the crew is thus (falsely) classified as qualified. Similarly, a false negative occurs when a crew's empirically measured performance does not meet the specified standard, despite the fact that their true ability is more than adequate with regard to the standard; in this case the crew is (falsely) classified as not qualified. These two manifestations of error of measurement are dealt with at length in Wheaton, et al., (1977). The purpose of the present report is to explore sources of measurement error which are important to the model Table VIII, and to consider methods of ameliorating their effects.

WEAPON SYSTEM DISPERSION

Anyone who has studied tank gunnery, and particularly performance measurement in tank gunnery, has come across weapon system dispersion effects. These effects may be characterized most simply by saying that the round doesn't always go where it is aimed. They are documented in several Army publications (e.g., FM 17-12-2, 1977, and in a set of theoretically derived tables from AMSAA), and are ascribed to such things as "tube droop," gun tube wear, and variability in propellant charge. Little guidance is given on how to cope with such random effects. For example,

> There is no way the crew can compensate for this [dispersion], but they should be aware of dispersion. If a round misses the aiming point by a slight amount, a re-lay with no adjustment in sight picture may achieve a target hit. This can only be determined by extensive crew experience (FM 17-12-2, 1977, p. 27).

Dispersion is of special concern in the present project as a potential source of error of measurement, and as a contributor to false positive and false negative errors. Concern about dispersion arises because the strike of the round is not totally determined by the gunner's skill. He may (sometimes) get a hit when his aim is poor, and conversely, he may (sometimes) miss when his aim is perfect. The extent of such inconsistencies between the gunner's true level of skill and his measureable performance based on the strike of the round depends on the magnitude of the dispersion produced by the weapon system. Suppose that the dispersion effect is such that the weapon system can hit the target, given the aim of the gunner is perfect, 90% of the time. Further assume that the gunner's skill is such that he will aim perfectly 95% of the time. The probability that he would actually hit the target on any given engagement in this case is 85.5% (.90 x .95 x 100). In other words, his measured performance will be 85.5% despite the fact that his true skill level is 95%. In developing the accuracy (or hit) standards of competence for the Table VIII it became apparent that, for whatever standard was selected, if the dispersion effects were of sufficient magnitude, they could lead to significant error in determining crew qualification.

ERROR OF MEASUREMENT AND CREW QUALIFICATION

During the course of this and earlier projects, Armor personnel have often commented for various engagements that, "while crews ought to be able to hit the target 85% of the time, they in fact cannot." When pressed on the issue, what becomes clear is that the limiting factor in tank gunnery often may not be crew competence, but rather the weapon system itself when used as a measuring instrument. Thus, while it might be possible for certain crews to theoretically attain even 100% competence in one or another kind of engagement, when tested they might hit the target less frequently than expected; this discrepancy would be due to the tank rather than the crew. The problem is not one of boresighting or zeroing (over which the crew has control and for which they are responsible) but rather lies in the fact that, from round to round, there is variability in the weapon system. To the extent that the round does not go precisely where it is aimed, error of measurement is introduced. If this error of measurement is severe enough to reduce system accuracy, for example to a level lower than that expected for the true competence of crews, live-fire scores may be seriously biased, and therefore inadequate measures of crew qualification.

Since the primary purpose of the model Table VIII is to measure crew qualification, and since live-fire performance measures might potentially bias or otherwise compromise the adequacy of the table for this purpose, a preliminary exploration of the problem has been undertaken using existing data. These data, while not ideal for the purpose, were sufficient to determine whether or not a problem exists, to grossly estimate the magnitude of the problem, and to suggest some possible solutions. The remainder of this paper describes the method by which the data were collected and analysed, the results of the analysis, and a discussion of the implications of these results. The final section of the paper qualifies the findings based on shortcomings in the procedures, and suggests precise approaches to further research.

It should be emphasized at the outset that the empirical results presented herein must not be taken as final, since the population tested is so small (i.e., one tank and one kind of ammunition). Nevertheless, the results do characterize the magnitude of the problem, and suggest further study.

METHOD

In order to support the study a set of engagements was required in which the strike of a tank round could be compared directly to where the crew aimed the round. Given these two pieces of information for a series of engagements it would be possible to measure the magnitude and/or biasing effect of the error of measurement, and to assess its significance when using hit/miss data to estimate crew competency for gunnery qualification.

The U.S. Army Armor Engineer Board at Fort Knox recently conducted a series of experiments on various tank suspension systems in which the type of data required for the present investigation was collected. During Phase I of this test a single instrumented, stabilized tank, equipped with the standard suspension system, was test fired extensively by two crews under a number of conditions. Each engagement was fired at a 2.3 x 2.3 meter target superimposed on a 6.1 x 6.1 meter cloth panel. An aiming cross with legs approximately 1 meter wide and 1 meter tall was centered on the target (see Fig. 1). According to the study design, each crew fired twenty rounds, two at a time, at the target from a stationary position at a range of 1500 meters. Each crew also fired approximately twelve, four-round engagements at the target while the tank was on the move; the following conditions of tank motion were examined (16 rounds per condition):

10 mph over a secondary road;
10 mph over moderate cross-country (2.5 RMS) terrain; and
5 mph over moderate cross-country (2.5 RMS) terrain.

The moving tank engagements were fired frontally at ranges of 1091 to 805 meters. Armor defeating ammunition was used throughout the test.

The test tank was carefully boresighted at the beginning of the data collection period. It was zeroed each day that testing occurred. Further, a check round was fired each time crews were exchanged; if necessary, the tank was then re-zeroed.

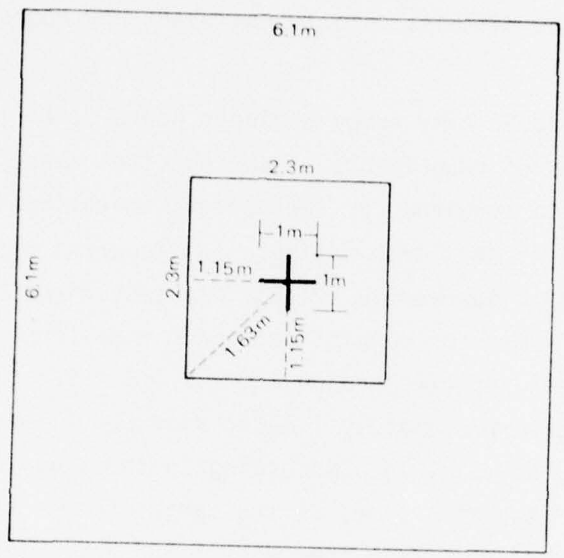

Figure 1. Target with aiming cross superimposed on cloth panel.

The typical scenario for the stationary engagements began with the tank commander's fire command. At this point the main gun was slewed onto the target, the gunner made a precise lay, and fired the first round of the engagement. He then relayed on the target, and fired the second round. The tank commander then issued a cease-fire command to end the engagement.

The scenario for the moving tank engagements was similar. The tank began moving down a predetermined course toward the target. The tank commander issued a fire command, and the gunner commenced fire; he attempted to fire up to four rounds while closing on the target. The tank commander issued a cease-fire when the fourth round was fired or when the tank approached the end of the course (approximately 800 meters from the target). During the engagement each crew member performed his normal duties. This included the driver who maintained the correct speed according to the experimental condition and warned of terrain features (e.g., dips and holes) over the intercom.

Because of practical circumstances the actual number of engagements and rounds fired was somewhat at variance with the original design. Table 1 presents the actual number of rounds fired by each crew under each condition. Not all of the rounds fired could be scored because of target obscuration caused by muzzle blast; the number of rounds actually scored, therefore, is presented separately in Table 1 for each condition.

Data were acquired for each round fired by means of video instrumentation. A television camera with a telephoto lens was aimed at the target and the strike of the round was recorded on a video tape recorder (the "Overwatch" system.) Personnel attached to the Armor Engineer Board determined the position of the strike of each round in the following manner: The tape was replayed using a television monitor, and the strike was observed. The tape was then backed up by hand until the frame which showed the round actually penetrating the target panel was found. Using the 2.3 meter target square and the 1 meter cross as references,

TABLE 1

Number of Rounds Fired by Each Crew Under Each Condition

(scorable rounds indicated in parentheses)

Engagement Type	Crew 1 Rounds		Crew 2 Rounds	
	Fired	Scored	Fired	Scored
Stationary/Stationary	20	20	20	20
Moving/Stationary 10MPH, Secondary Road	12	12	16	16
Moving/Stationary 10MPH, Cross-Country	14	13	16	16
Moving/Stationary 5MPH, Cross-Country	16	15	12	11

the vertical and horizontal distances from the center of the target to the point of penetration were then determined in centimeters. When the round missed the entire cloth panel, it was scored as lost and assigned an arbitrary vertical and horizontal score (998 cm). These "overwatch" data were supplied to the project staff.

In addition to strike data the range-to-target was determined for each engagement. All stationary engagements were fired from 1500 meters as determined by range survey. The range for moving engagements was determined in the following manner: Prior to firing, marked stakes were placed at five meter intervals along the tank course. During firing, a scorer rode along on the tank's turret bustle; when a round was fired he dropped a sand bag. A second vehicle came down the course behind the firing tank and determined the range to target by comparing the position of the sand bag relative to the marker stakes. The resulting range data were used to transform strike data from centimeters to mils and vice versa.

Crew performance was simultaneously measured via a gun camera system developed by the Instrumentation Branch of the Armor Engineer Board. A television camera was mounted in the turret of the tank through the gunner's infrared periscope. This periscope is yoked to the gunner's daylight periscope via a prismatic beam splitter, so that with the proper alignment the camera view is identical to the gunner's view. The camera signal was transmitted via an RF link to a video tape recorder in a remote instrumentation van. The video tape thus recorded the gunner's view, including where he positioned the periscope reticle on the target; superimposed on the recording were electronically-generated time, date, and condition data for reference purposes. The sound track of the tape contained the actual intercom conversations of the crew during firing.

The aiming performance for each round was measured in the following way: The tape of a single exercise was observed until the round was actually fired; the moment of firing was easily determined since the monitor screen would "white-out" due to the muzzle blast. The tape was then wound back by hand to the frame immediately preceding the "white-out". The gunner's aim was then scored on this frame in terms of azimuth and elevation from target center, using the periscope reticle as a reference. The resulting "aiming errors" were expressed in mils. The gun camera tapes were scored using the concensus of two project staff members who worked together following initial practice.*

*A preliminary pilot study indicated that the scoring could be performed with high reliability. Agreement among analysts represented by inter-scorer correlations ranged from .779 to .954 for the first 40 rounds scored independently by each of three scorers, and average disagreements were less than .1 mils.

ANALYSIS AND RESULTS

The first step in the analysis was to examine the relationship between the aiming point and the strike of the round for each engagement. The degree of correspondence between them would indicate the validity of using strike data to represent crew aiming performance. After converting all measurements to mils*, the aim and strike azimuth data and the aim and strike elevation data were correlated. These correlations were computed for all engagements combined and for each kind of engagement separately. They are presented in Table 2, together with the number of engagements included in each correlation.** While many of these correlations are significant, they are nevertheless disappointingly small. When the proportion of variance accounted for is considered (the squared correlation coefficient), it becomes clear that the strike of the round may be insufficiently related to aiming to be used as a measure of performance. For example, the largest correlation obtained (.788) when squared yields a value of .621. This figure can be interpreted to mean that 62.1% of the variation in where the round struck was accounted for by the point of aim. Overall, aiming accounts for less than half of the variability in elevation of the strike of the round (41.3%), and even less of the variability in azimuth (14.8%). For each of the kinds of engagements, the proportion of variance accounted for ranges from a high of 62.1% to a low of 5.6%.

---

* Since the engagements occurred at varying ranges, it was first necessary to convert the strike-of-the-round data (in centimeters) to mils so that data from engagement to engagement could be compared. This was accomplished by dividing azimuth and elevation strike error (in centimeters) by the range of the engagement, and multiplying the result by 10. Thus, 100 centimeters error at 1000 meters leads to (100/1000) x 10 = 1 mil. Similarly, 150 centimeters at 1500 meters leads to (150/1500) x 10 = 1 mil.

** Since the azimuth, elevation, and distance dispersion measures all depended on comparing aim with strike, engagements on which the strike of the round was not precisely scorable were excluded from the succeeding analyses. This led to the loss of data on 11 secondary road, 10 mph engagements and 1 cross-country, 10 mph engagement.

TABLE 2

Correlations Between Point of Aim and Point of Strike

(number of engagements in parentheses)

Engagement Type	Azimuth	Elevation
All	.385 (111)***	.643 (111)***
Stationary	.536 (40)**	.237 (40)
Moving 10MPH, Secondary Road	.420 (17)	.651 (17)*
Moving 5MPH, Cross-Country	.684 (26)***	.713 (26)***
Moving 10MPH, Cross-Country	.320 (28)	.788 (28)***

* $p \leq .01$
** $p \leq .001$
*** $p \leq .0001$

In other words, what this simply means is that, while the location where the round strikes is partially related to the aiming point, there is also a great deal of variation in the position of the strike which bears no relation to the aiming performance of the gunner.

This issue may be examined in another way by considering on a round-by-round basis whether each round was aimed within the target square, and whether it struck within the target square. In other words, what was the relationship between hit/miss performance in terms of aiming and in terms of strike of the round? Table 3 presents this information for each condition of firing, and for all conditions combined. For each condition, the row entries correspond to the frequency with which the gunner's aim was within the 2.3 x 2.3 meter target, that is, whether or not he aimed so as to obtain a hit. The column entries indicate the frequency of hits and misses actually obtained, based on the strike of the round. Assuming that the gunner's aim reflects his actual competence, and that one desires to score his competence based on the strike of the round, it would be desirable that the round would hit whenever he aimed within the target, and that the round would miss whenever he aimed outside the target square. In this perfect situation, one would find all of the engagements tabulated on one diagonal in each of the five data arrays shown in Table 3; that is, each round aimed as a "hit" (within the target) would strike as a hit, and each round aimed as a "miss" (outside the target) would miss. To the extent that there is appreciable dispersion in the weapon system, error of measurement would be introduced in using the strike of the round to score, for example, the gunner's aiming performance. In this case, somewhat less than all of the well-aimed shots would strike the target as a hit, and somewhat less than all of the poorly aimed shots would miss the target.

The data in Table 3 indicate that, overall, when the gunner aimed so as to hit the target, the round hit only about 83% of the time, and when he aimed so as to miss the target, the round missed the target only 56% of the time. When considering strike-of-the-round data as indicators of aiming performance, these results would lead one to conclude

TABLE 3

Relationship Between Aim and Strike with Reference to the 2.3 X 2.3 Meter Target Square

Engagement Type	Gunner's Aim	Strike of the Round Miss	Strike of the Round Hit
Stationary Tank	Miss	1	1
	Hit	3	35
Moving Tank, 5MPH Cross-Country	Miss	0	2
	Hit	2	22
Moving Tank, 10MPH Secondary Road	Miss	3	3
	Hit	8	14
Moving Tank, 10MPH Cross-Country	Miss	5	1
	Hit	5	18
All engagements	Miss	9	7
	Hit	18	89

erroneously on 17% of the engagements that the gunner had aimed incorrectly, and on 44% of the engagements that he had aimed correctly. Such erroneous conclusions are precisely what leads to misclassification errors, false-negative errors in the former case and false-positive errors in the latter.

These findings may be summarized by considering, under each condition, the probability that the round went where it was aimed (whether it was aimed as a hit or a miss). Overall this probability was 79.7%. For the stationary tank condition the probability was 90%; for the moving tank at five miles per hour cross country it was 84.6%; the probability was 60.7% at ten mph over a secondary road, and 79.3% at ten mph cross country.

From these results and the preceding correlations, it appeared that the strike of the round did not correspond very well with the crew's accuracy of aim, thus potentially introducing a fairly large error of measurement when target hits are used as a scoring criterion for determining crew qualification.

The next step was to further characterize the nature of this error, and to determine whether it might actually preclude the use of strike data as an acceptable estimator of crew competence. Toward this end the data were algebraically transformed to simulate a hypothetical "perfect" gunner. Note that if a gunner aims two mils right, and the round falls four mils right, the round has deviated two mils right. This is equivalent to the situation where the gunner aims dead on, and the round falls two mils right; in both cases the dispersion from the point of aim is two mils right. Similarly, the case where the gunner aims dead on and the round falls dead on is equivalent to the case where the gunner aims 1 mil high and the round falls 1 mil high; in both of these latter cases the round has fallen where it was aimed, and the deviation or dispersion is zero. By calculating these deviation or dispersion measures, one may then examine the impact of main gun dispersion independent of actual gunnery competence.

The conversion is quite simple. The deviation in azimuth is obtained by subtracting the azimuth of aim from the azimuth of strike; thus in the example above, a strike 4 mils right minus an aim 2 mils right leads to a deviation of 2 mils, and a strike 2 mils right minus an aim of 0 mils right leads to a deviation of 2 mils right. Similarly for elevation dispersion, a strike 3 mils short minus an aim of 1 mil over leads to a deviation of 4 mils short. Treating left azimuth and short elevations as negative, one recreates the data matrix as though all of the crews had performed perfectly, and the only error is the error of measurement introduced by the weapon system. In addition to considering these data in two Cartesian dimensions (azimuth and elevation), it was also possible to derive a single measure, distance from the center of target, by applying the Euclidean distance formula to these data:

distance = square root of (azimuth deviation squared + elevation deviation squared).

After transforming the data to create a dispersion distribution for the hypothetically perfect gunner, the next step was to examine the mean deviations, in azimuth, elevation, and distance, of the strike from the point of aim. The mean deviations for each kind of engagement and all engagements combined are presented in Table 4. Also included in this table are $\underline{t}$ statistics and significance values for tests of the assertion that the mean deviations are not significantly different from zero.

The data in this table reveal a number of things. First, the average azimuth, elevation, and distance deviations differ significantly from zero in several cases. The average azimuth and elevation deviations are all negative, indicating a tendency for the round to move to the left and down from the aiming point. The consistency of this finding suggests that there is a relatively systematic component of the observed dispersion, as might be expected from a failure to boresight or zero correctly, or from a phenomenon such as tube droop which develops during firing. Since the test vehicle was carefully boresighted before the test, and confirmation rounds were fired fairly frequently, it seems unlikely that the align-

TABLE 4

Mean Deviations of Strike from Aiming Point (in mils) for the Hypothetically Perfect Gunner

Engagement Type	Mean Azimuth Deviation	t - statistic (df)	Mean Elevation Deviation	t - statistic (df)	Mean Distance Deviation	t - statistic (df)
All	−0.204	−2.11 (110)*	−0.139	−1.88 (110)	0.947	11.13 (110)***
Stationary	−0.058	−0.96 (39)	−0.039	−0.34 (39)	0.550	5.71 (39)***
10MPH, Secondary Road	−0.654	−4.18 (16)***	−0.390	−3.47 (16)**	.970	8.06 (16)***
10MPH, Cross-Country	−0.006	−0.02 (27)	−0.097	−0.50 (27)	1.540	6.03 (27)***
5MPH, Cross-Country	−0.348	−2.90 (25)**	−0.173	−1.25 (25)	0.905	10.86 (25)***

* $p \leq .05$
** $p \leq .01$
*** $p \leq .001$

ment of the weapon and sights is at fault. In any event, this down-and-to-the-left component is not the entire explanation of the variation between aim and strike.*

The distance dispersions, representing the combined azimuth and elevation effects, are fairly substantial, and are always significantly greater than zero. Another way of considering these data is with respect to the target used in the present study at, for example, 1500 meters. A deviation in distance of 115 centimeters (1/2 of the target width) for a perfectly aimed round would put the strike of the round all the way out at the edge of the target square, or .767 mils away from the center of the target and point of aim. The overall average distance deviation in Table 4, however, is .947 mils indicating that many rounds, though aimed at the center of the target, may miss entirely.

Another way of looking at dispersion effects was to determine the probability distributions for various strike-from-point-of-aim distances. These data are shown in Figure 2 where each vertical bar represents the proportion of rounds, as indicated on the scales at the left of the figure, which fell at various distances from the point of aim, as indicated at the bottom of the figure. Also note that the numbers at the bottom of the figure show the distances in centimeters that correspond to the distances in mils at various ranges. Thus, for those rounds which disperse between 1 and 1.25 mils, this corresponds to rounds which travel 201 to 250 centimeters from the point of aim at a range of 2000 meters.

---

*From the correlational analyses and the variances of the aim-strike deviations, it is clear that the down/left phenomenon is only a tendency, and that not all rounds deviate systematically in this one direction. Further, the proportion of variance in strike-of-the-round which was not accounted for by aim (1.0 minus the squared correlation coefficient in the earlier correlational analyses---see Table 2) cannot be totally due to any such tendency, as the correlation coefficient is generally insensitive to constant differences in two variables being correlated. The non-constant dispersion suggested by the correlation coefficients is of sufficient magnitude that it cannot be ignored.

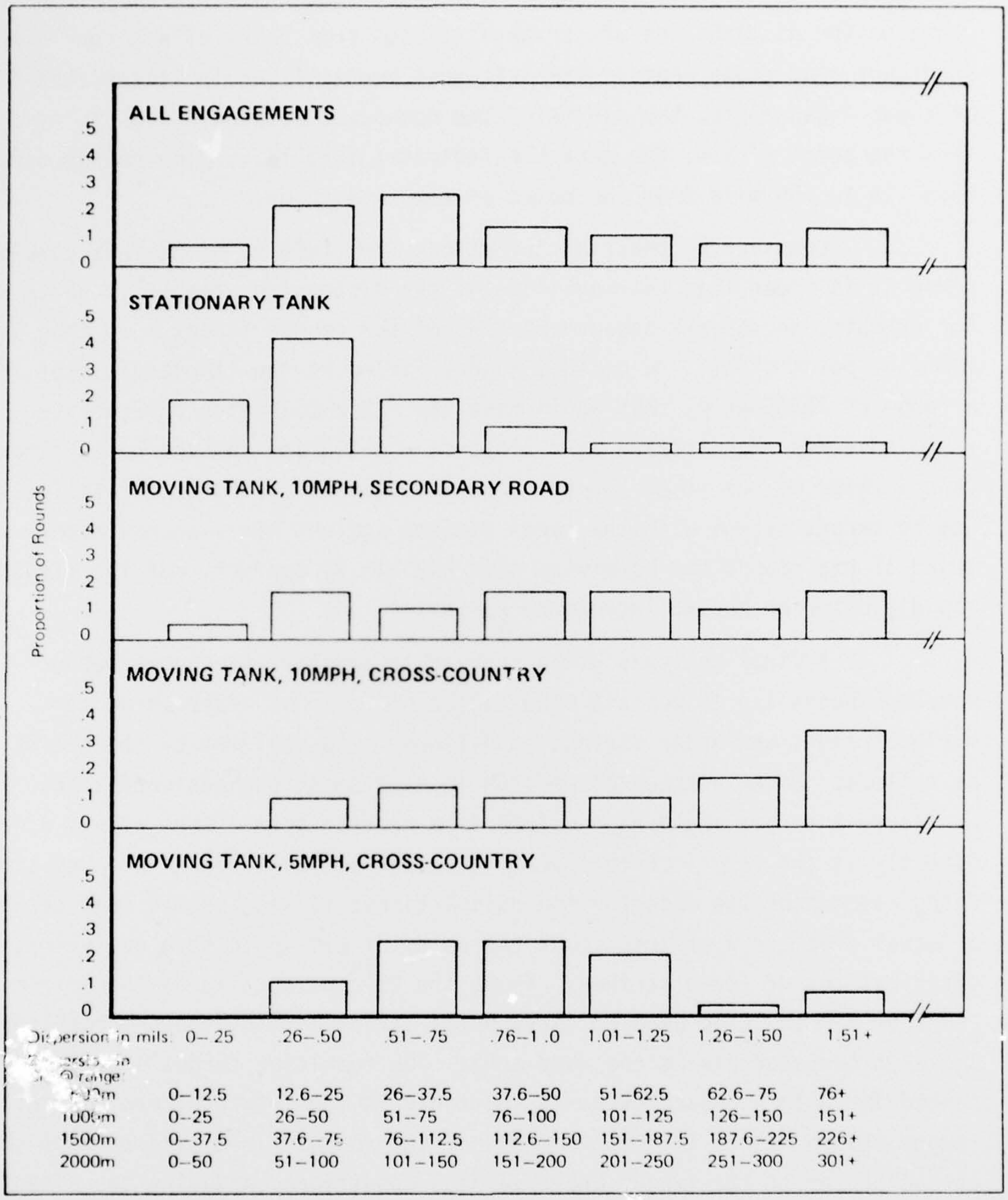

Figure 2. Proportion of rounds at various distances from the aiming point.

To interpret the figure, for example, consider the third row of entries which contains the distribution of strike distances from point of aim for 10 mph, secondary road engagements. The left-most vertical bar indicates that in 6% of these engagements, the strike of the round was between 0 and .25 mils from the point of aim; the next bar indicates that 18% of the rounds struck from .26 to .50 mils from the point of aim, and so on.

Considering these distributions from left to right in a cumulative sense it is clear that the magnitude of the dispersion problem is quite severe. For example, across all engagements 34% of the rounds struck more than 1 mil from the point of aim. A perfect gunner firing at the standard target from a range of 1500 meters thus would miss the 2.3 x 2.3 meter square (i.e., would have his round strike at a distance $\geq$ 150 cm from the center) more than a third of the time. Thus the perfect gunner firing at a relatively nearby target begins with the cards stacked against him---approximately one-third of his rounds may be misses when his aim is perfect, and the situation rapidly deteriorates at increasing ranges.

A final analysis was performed to examine the kind of error envelope necessary to contain this degree of error of measurement at various ranges and under various conditions. The goal may be thought of as follows: Given a known dispersion in mils under various conditions, how large a target would be required if a perfect gunner (who always aimed directly at the target center) were to obtain at least 95% hits? One simplifying assumption was made for the calculations; it was assumed that targets of equal area and symmetric about the point of aim would have equivalent distributions of round strikes. Thus, the 95th percentile distance from point of aim could be used to construct a target circle, and a target square was then computed having the same area. The resulting target sizes are presented in Table 5. Each entry in the table is the length of one side of the target square needed to "capture" 95% of the rounds fired by a perfect gunner at the center of the target under various conditions, assuming the dispersion distributions found in the present data.

TABLE 5

Target Size (cm) Necessary for a Perfect Gunner to Obtain 95% Hits

Range (meters)	Engagement Type: Stationary	10MPH Secondary Road	10MPH Cross-Country	5MPH Cross-Country
800	143	227	367	233
1000	179	284	459	291
1200	215	340	551	349
1400	251	397	643	407
1600	286	454	735	465
1800	322	510	826	523
2000	358	567	918	581
2200	394	624	1010	640
2400	430	681	1102	698
95th Percentile Radius (in mils)	1.01	1.60	2.59	1.64

The same information is also shown in Figure 3. The size of the standard target square is indicated by the darkly shaded area, and the size of the full target panel by the lightly shaded area. This figure indicates that the target square used in the current study may provide a 95%-accurate estimate of gunnery performance only for stationary exercises out to 1200 meters, and 5 mph cross-country and 10 mph, secondary road exercises out to 800 meters. Even the entire target panel is inadequate for many moving tank exercises at moderate-to-long ranges. As an alternative to larger targets, one could also decrease the target range. If this were done, the moving exercises examined in the present study could be fired at from 400 to 800 meters, in which case the perfect gunner could be expected to obtain 95% hits.

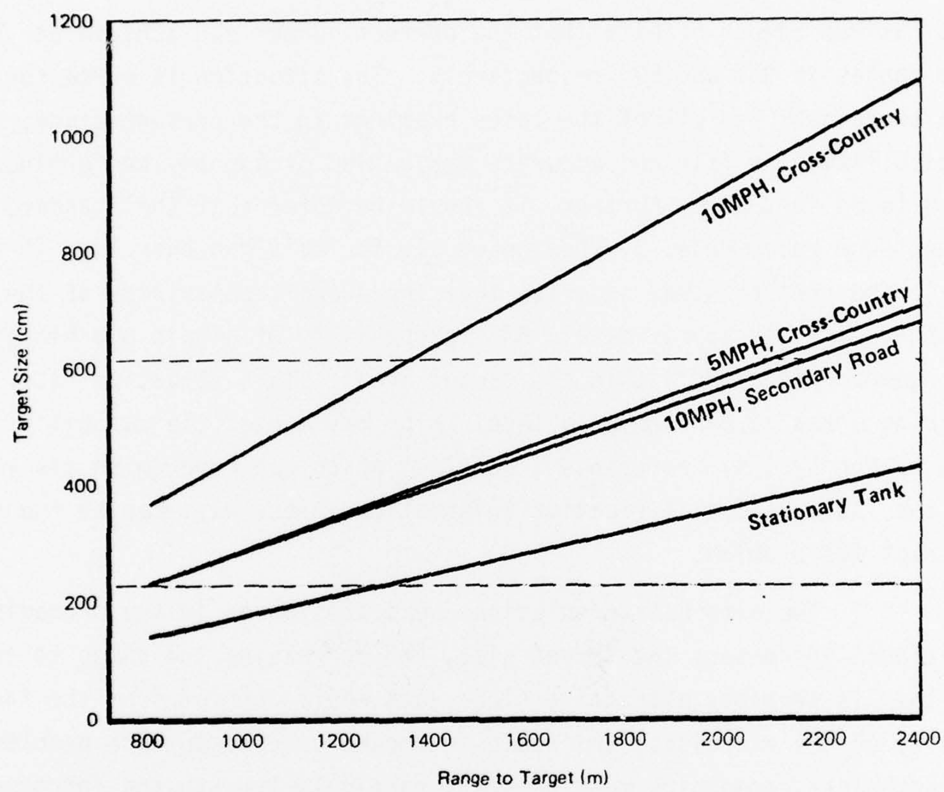

Figure 3. Target Size Required for 95% Hits by a Perfect Gunner.

DISCUSSION

The findings of this exploratory study seem clear---hit/miss data collected under live-fire conditions similar to those found in the current Table VIII lead to inaccurate estimates of crew performance capabilities. In the best of circumstances a perfect gunner, firing from a stationary tank, will miss the 2.3 x 2.3 meter target square about 5% of the time at 1000 meters, and 20% of the time at 2000 meters. Therefore, the maximum number of hits that the perfect gunner can achieve at these two ranges is 95% and 80% respectively. The situation is worse for moving exercises. In all of the cases examined in the present study, the possibility of a fair and accurate evaluation of gunnery performance would seem to be in doubt. Further, it should be noted that the standard of competence recommended by Wheaton et al. for main gun exercises is 95%, while the present study suggests that the overall capability of the weapon system is approximately 83% (probability of a main gun hit given the gunner has aimed within the target area). This situation (i.e., requiring crews to perform at a level which may exceed the capability of the weapon system) represents a conflict which can compromise the validity of the Table VIII qualification information unless ways can be found to correct the problem.

Two alternative solutions were considered in the preceding section: increasing the target size, and decreasing the range to target. Neither is terribly attractive since each would detract from the face validity of the exercises, and could introduce user acceptance problems. Nevertheless, something must be done, particularly with the introduction of a criterion-referenced model Table VIII. For a variety of reasons the scores required to qualify on this table are likely to be quite high, and the dispersion effects of the weapon system, if not adjusted for, could make qualification impossible, or largely a matter of luck. One novel approach to dealing with the problem is the subject of study in the second phase of the current project. This phase, which is concerned with simulated testing of Table VIII, includes plans to examine the feasibility of scoring gunnery performance based directly on aiming data. A gun camera system would be used similar to the one employed in collecting the present data. The direct scoring of aiming performance eliminates the dispersion effects associated with strike-of-the-round data and circumvents a number of other live-fire scoring problems not specifically addressed in this report.

One must, of course, remain quite cautious in interpreting the results presented herein. As indicated above, this study is at best exploratory, since only one tank was tested, and only one kind of ammunition was employed.* Further, the gun camera technique is of recent origin, and several shortcomings are possible. For example, while the mount used to hold the video camera in alignment is quite sturdy, little data are available regarding its ability to hold its position perfectly over the course of many main gun firings. In addition, while the video tape images used for scoring appear to be continuous, they are in fact made up of individual frames, much as a standard movie film. The possibility exists that there may be a shift in aiming point between the time of the last frame prior to firing (the frame scored) and the actual time of firing. The possibility that such shifts produced the dispersion effects was explored by examining informally the shifts in aiming point between the last and second-to-last frames for a number of engagements; while shifts occurred, they seemed to be generally quite small. Further, most of the dispersions (over 40%) were short and left; if the frame-to-frame shift were responsible for the dispersion effects, it would imply that gunners were tracking down and left onto most of the targets. Nevertheless, because of the relatively slow frame rate of the video recorder (approximately one frame every 63 milliseconds), the possibility of this kind of error exists.

*While only two crews were tested, this is not a limitation, since crew performance is factored out of the central analyses by computing the distance between point of aim and point of strike of the round.

Despite these and other uncertainties about the present data, the indication that dispersion effects may hamper the measurement of crew capabilities is strong enough to warrant further research. The next step should be to further verify the accuracy of the gun camera instrumentation for assessing sight pictures. Video recorders with higher frame rates might be required. Alternative techniques might also be considered such as using a still camera mounted to the gunner's infrared sight and linked to the firing circuit to expose a single frame of the sight picture as the gun fires; timing would be critical in order to avoid problems with gun tube flash and obscuration.

Once the instrumentation for determining sight picture has been established, the next recommendation would be to fire sequences of engagements much as occurred in the present study, but using a randomly selected sample of tanks, as well as a random sample from each type of main gun ammunition (e.g., from several different manufacturing lots). One would also want to examine environmental conditions such as temperature, which might impact on the gun tube geometry, and wind speed. Data should be collected under the range of conditions called for in the model Table VIII (Wheaton, Fingerman, & Boycan, 1977).

The data collected in such a study would be analyzed much as was done here (see Tables 2 through 5 and Figures 2 and 3). The goal would be to verify the findings of the present study and to assess the validity of using sight picture data rather than live-fire hit/miss data in scoring crew competence.

REFERENCES

U.S. Army Armor School (USAARMS). Tank gunnery for M60, M60A1, M60A1(AOS), and M48A5 tanks. Field Manual (FM-17-12-2), Washington, DC: Headquarters, Department of the Army, 1977.

Wheaton, G.R., Fingerman, P.W., & Boycan, G.G. Development of a model tank gunnery test (draft). Arlington, VA.: U.S. Army Research Institutes for the Behavioral and Social Sciences, 1977.